USAWC STRATEGY RESEARCH PROJECT

Battlefield Radars in the 21st Century Army

by

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The views expressed in this academic research paper are those of the author and do not necessarily reflect the official policy or position of the U.S. Government, the Department of Defense, or any of its agencies.

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ABSTRACT

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Technological advances in the computing power of microprocessors will allow weapons locating and air defense radar capabilities to be integrated into a single platform. This innovation will have a synergistic effect by allowing the commander the ability to easily network air defense and weapons locating sensors into the intelligence sensor grid, and concurrently reduce the logistics footprint. The purpose of this research project is to examine the feasibility of developing a radar network architecture on a future battlefield that would reduce the force structure, lower acquisition cost, and improve logistics.

In determining the feasibility of developing a cost effective networked radar architecture, material developers must take four factors into consideration: system requirements for the radar, application of network centric warfare, formulation of an integrated intelligence sensor grid, and the tactical employment of the radars within the battle space.

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BATTLEFIELD RADARS IN THE 21ST CENTURY ARMY

> The overarching focus of Joint Vision 2020 is full spectrum dominance—achieved through the interdependent application of dominant maneuver, precision engagement, focused logistics, and full dimensional protection. Attaining that goal requires the steady infusion of new technology and modernization and replacement of equipment. However, material superiority alone is not sufficient. Of greater importance is the development of doctrine, organizations, training and education, leaders, and people that effectively take advantage of the technology.[1]
>
> —Joint Vision 2020

> Colonel Georg Bruchmüller was one of the first practitioners of massed fires independent of massed guns. He was one of the first to use artillery effectively against distant targets, and he can be considered one of the fathers of the concept of deep operations. Yet in many ways he was too far ahead of his time. Most of his concepts only reached maturity in subsequent years with the technological evolution of communications systems, battlefield mobility, target acquisition, and more sophisticated munitions.[2]
>
> —Steel Wind

Innovations in tactics and doctrine are the products of innovative thinkers like COL Bruchmüller who had the vision to see beyond his forces' current capabilities to develop new concepts for the Field Artillery. History teaches that new technologies and weapon systems are enablers, but innovative concepts and doctrinal changes drive true transformation.[3]

During World War II, the Royal Air Force and U.S. Army Air Corp concentrated their efforts on developing the strategic bomber as the platform of choice and missed the opportunity to transform joint warfighting through air power.[4] The Germans capitalized upon this oversight and made significant gains in the early battles of World War II through the innovative use of armor, infantry, and air power as a joint force.[5]

With the development of the first radar during World War II, British scientists focused only on tracking aircraft and ship movements. It was innovative thinkers at Fort Monmouth, New Jersey who transformed the radar's use and applied the technology to build the first counterfire radar to detect hostile indirect artillery and mortar fire. This concept revolutionalized counterfire on the battlefield and lead to the development of responsive and accurate counterfire radars.

These counterfire radars were later adapted to perform the mission of air defense and provide a significant stand-off range for deployed divisions.

Technological advances in the computing power of microprocessors now facilitates combining both weapons locating radar and air defense radar capabilities into a single platform. This innovation will have a synergistic effect in battlefield strategy by facilitating a commander's ability to easily network air defense and weapon locating radars (sensors) to enhance the intelligence gathering capability and concurrently reducing the logistics footprint. The purpose of this research project is to examine the feasibility of developing a radar network architecture on a future battlefield that would reduce the force structure, lower acquisition cost, and improve logistics.

BACKGROUND

No one can pinpoint the precise starting date for radar development; however, in 1864 British physicist James Clerk Maxwell developed a set of equations governing the behavior of electromagnetic waves.[6] Twenty-two years later, in 1886 German physicist, Heinrich Hertz, used these equations to demonstrate the laws of radio-wave reflection in a number of experiments.[7] While a great deal of research was conducted with radar principles in the early 19th century, it was not until 1935 when British physicist Sir Robert Watson-Watt implemented a practical application in a radar system called Radio Direction Finding.[8] This application was adapted in 1940 by both Britain and the U.S. to create a defensive weapon to detect incoming planes and also as an offensive weapon installed in aircraft to allow pilots to fly at night or through limited or no visibility.[9]

When the AN/MPQ-10 counterfire radar made its début during the Korean War in 1951, it was a true enabler, allowing the Army's Field Artillerymen to maximize the effects of weapons locating radars as a counterfire asset. Just as technology had been an enabler during World War II, these new radars allowed the artillery to maximize their effectiveness in mass fires by quickly locating hostile indirect artillery fire. Modifications to doctrine, tactics, and training drove the artillery community to improve its counterfire radar system. Consequently, in the years to follow, the counterfire radars were upgraded to the AN/MPQ-4 radar, thus improving its capabilities and sustainability. As the battlefield became more dynamic, a more responsive capability was required, and Fort Monmouth answered the call with the development of the AN/TPQ-36 and AN/TPQ-37 Firefinder radars.

During both Vietnam and Desert Storm, the Firefinder radars were invaluable to the Field Artillery in detecting and accurately locating hostile indirect mortar and artillery fires. In his review of the after action reports from Desert Storm, Major General Fred F. Marty, then Chief of Field Artillery, acknowledged that the Firefinder radars decisively engaged the Iraqi artillery.[10] Many of the Desert Storm Targeting Officers and Artillery Commanders attribute Firefinder with silencing the Iraqi Artillery and rendering them combat ineffective for fear of being targeted.

Throughout the 20th century, the U.S. military's battlefield radars were highly effective in pinpointing the location of the enemy's indirect fire weapons and aircraft. This was a direct result of well defined requirements and a solid industrial base to support the development of military systems. The hardware and software requirements for the AN/TPQ-36 and AN/TPQ-37 Firefinder radars, the AN/MPQ-64 Sentinel radar, and the AN/TLQ-31 Air Traffic control radars were developed and fielded using the standard waterfall technique during the cold war era when each battlefield functional area, Field Artillery, Air Defense Artillery, and Army Aviation, had clearly delineated and set areas of responsibilities. This allowed developers to focus upon one set of requirements per system and facilitated the tight coupling of the hardware and software to increase performance. As a result, these systems were highly responsive for their respective "stovepipes," allowing them to engage the enemy with deadly precision and making them tremendous assets as target acquirers for their respective Battlefield Operating System (BOS).

20TH CENTURY BATTLEFIELD RADAR OPERATIONS

The 20th century battlefield radar's capabilities allowed them to be highly effective in managing the local battlespace because of their speed of operations within their "stovepipes." The Air Defense and Surveillance radars primary mission during this era was to protect against a hostile airborne force while concurrently ensuring friendly aircraft were not inadvertently targeted in the process. The weapons locating radars performed two basic missions: hostile weapons locating and tracking of friendly fires.

Under the 20th century force structure, a division had two air traffic control radars, six sentinel air defense radars, three AN/TPQ-36 short range Firefinder weapons locating radars, and two AN/TPQ-37 long range Firefinder radars. In this architecture, each radar was responsible for its specific area only. Again, the focus of the 20th century weapons systems was

speed and responsiveness. None of the systems had a requirement for target hand off, queuing of other assets (weapons or radars), or interfacing with intelligence systems.

In a three brigade division, a typical tactical scenario required the division to allocate one sentinel air defense radar and one Q-36 Firefinder radar per committed brigade. The division headquarters would retain the two air traffic control radars, three sentinel radars, and the two Q-37 Firefinder radars for the deep battle and counterfire fight. In this architecture, there were no horizontal communications between the radars; consequently, communications were limited to vertical communications between the radar and its command and control headquarters. Even with limited communications, these radars were tremendous assets to the division. The Firefinder radars were particularly valuable because of their multiple roles; i.e. they could do hostile and friendly tracking of artillery and mortars.

The Firefinder weapons locating radar has the ability to operate in one of two operating modes, hostile and friendly. For the majority of the time, these radars operate in the hostile mode. While in the hostile mode, the radars have a maximum search sector of 1600 mils (90 degrees) for the Q-37 and the Q-36, a 104 mil (6 degrees) vertical sector for the Q-37, and an 80 mil (5 degrees) vertical sector for the Q-36 radar. Any projectiles that break the radar beam and meet the target selection criteria are immediately tracked and passed to the controlling headquarters for possible engagement. In the friendly mode, the radar operates much like the hostile mode except it tracks outgoing projectiles and plots their impact points. Thus, it allows the warfighters to accurately determine if the artillery impact achieved the desires of the commander.

The Sentinel radars are "real-time" tracking assets which allow the division commander to have a complete view of the air picture. The radar interfaces with both the Air and Missile Defense Workstation (AMDWS) system for command and control and the Forward Area Air Defense Command and Control ($FAADC^2$) for engagement operations. When coupled with the AMDWS, Sentinel offers the Air Battle Management Operations Center (ABMOC) the ability to track and delineate between fixed and rotary aircraft as well as friendly and enemy aircraft. For the Avenger and Stinger platoons, Sentinel supports engagement operations by providing accurate targeting information for the gunners.

In their respective “stovepipes”, these 20th century battlefield radars performed yeomen service. They greatly enhanced the warfighter's ability to engage the enemy at extended ranges and to see deep, as well as during periods of limited visibility. The Army procured 130 Sentinel and 26 Air Traffic Control radars to perform the air defense and air space management mission and 92 short range AN/TPQ-36 Firefinder radars and 72 long range AN/TPQ-37 Firefinder radars over a period of 25 years.

RADAR FUNDAMENTALS

While their missions and operational techniques are different, weapons locating and air surveillance radars share many commonalities, such as their use of phased array antennas, similar operating architectures, and the same basic operating principles (see Figure 1).[11] For any functional radar, there are four basic elements? antenna, transmitter, receiver, and indicator/display.[12]

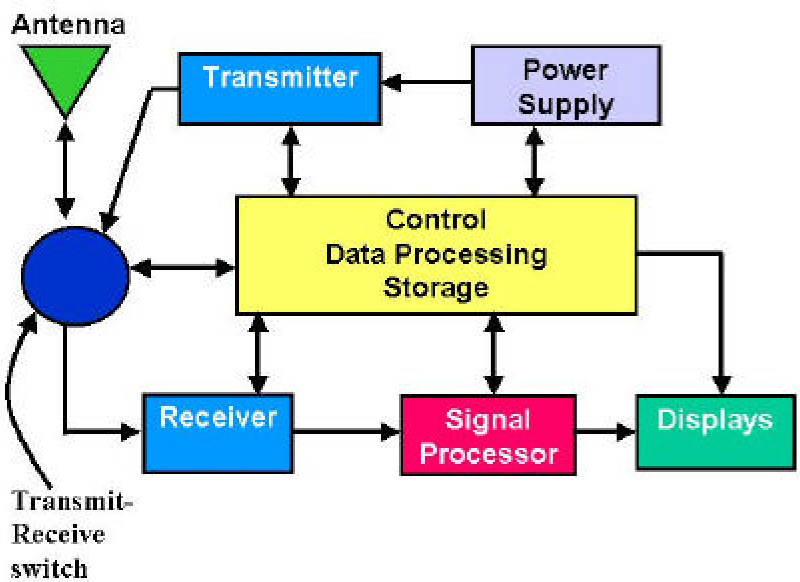

FIGURE 1 RADAR BLOCK DIAGRAM

The radar antenna serves two functions. First, it couples the Radio Frequency (RF) energy from the radar transmission line into the propagation medium and vice versa.[13] Second, it provides gain and radar beam directivity for both transmission and reception of the Electromagnetic (EM) energy.[14] Radars use two basic types of antennas, the dish antenna and

an array antenna.[15] Although they are more complex and less capable than the dish antennas, array antennas are the most cost effective for most military applications because they are able to track large numbers of targets, and they are electronically steerable, making them essentially inertialess.[16] When compared to the mechanical steering of the dish antennas, array antennas have a significantly lower maintenance requirement.

The radar transmitter generates the desired RF waveform at a required power level.[17] The required RF power can be obtained via two means, directly from a power oscillator, such as a magnetron; or it may be derived from an RF amplifier, e.g. traveling wave tube amplifier, crossed-field amplifier, etc.[18] The waveform is dictated by the specific system requirements, e.g. weapons locating, tracking, or surveillance.[19]

The radar receiver accepts weak target signals, amplifies the signal to a useable level, and then translates the resulting information contained therein from RF to baseband.[20] Generally speaking, there are four types of receivers: superheterodyne, superregenerative, crystal video, and tuned radio frequency.[21] Of these basic types, the superheterodyne is the most prevalent because of its sensitivity, high gain, selectivity, and versatility.[22]

The radar indicator or display conveys target information to the operator.[23] Normally the radar display is a two-dimensional screen that shows the location of the target with respect to a reference point.[24] The development of digital terrain elevation data (DTED) now allows the operator to see information superimposed on a digital map of a given area.

TECHNOLOGY FACTORS

In developing any battlefield radar, there are no major hardware or software differences that differentiate air surveillance, air defense, and weapons locating radars. The main differential of these radars are their specific missions. It is this differential which affects the complexity of the system, developmental cost, and total acquisition time required to build each system. Throughout the 20th century, the average build time for a radar was 24 months with the majority of the time being spent waiting for parts to fabricate major components. Had developers had a high demand for individual components, the build time could have been reduced significantly. For system development in the 21st century, material developers should require all radars to use common hardware and sound software engineering principles and

practices to increase flexibility, improve the speed of acquisition, and lower the radar's total acquisition cost.

HARDWARE CONSIDERATIONS

The use of common off-the-shelf hardware (COTS) and standardized system components offers a significant advantage to the production of battlefield radars. This concept seeks to minimize the impact of hardware changes or upgrades upon system development. Using COTS allows DoD to capitalize upon private industry's economy of scale and research budget.[25] Fundamentally, this means that DoD will be able to capitalize upon the advances and developments in process capacity. Also, standardizing the hardware components leads to the ability to use a standardized communication architecture. This standardization has helped developers overcome the technological challenges of multiple communications protocols. This standardization has lead to a revolution in how platforms communicate on the battlefield.

Standardizing upon common hardware allows the Army to channel its logistics efforts. With standardized hardware, logisticians no longer have to maintain multiple versions/types of the same computer/part but instead can maintain stockages of single items. The implementation of standardized communications protocols in the 1990s, conquered the technological challenge facing developers. Consequently, there is no valid reason why all battlefield radars cannot share common hardware.

The Army's Recapitalization program of the AN/TPQ-36 Antenna is a prime example of the benefits of shared components. Both the AN/TPQ-36 Firefinder and AN/TPQ-64 Sentinel will share six of the same major components. This sharing will reduce the logistical burden to maintain separate major components. For the past 15 years, there has been separate Traveling Wave Tubes (TWT) for each type of radar at an individual cost of $36,000. By sharing the same TWT, the Army's Logistics Command will be able to cut stockages by 50%, resulting in a net savings of $0.5 million dollars to stock two different TWTs.[26]

Another example of shared component usage is the experimental Multi-mission radar being developed by the Communications and Electronics Command (CECOM), Research and Development Engineering Center (RDEC). The major idea behind this radar is that the Air Defenders and Field Artillerymen will share exactly the same hardware, but their mission functions will be software selectable as to which mission is primary, target acquisition or air

defense. The system's primary specifications for the target acquisition mode are secondary requirements for the radar in the air defense/surveillance mode and vice versa. Requiring that the material developers build radars that are capable of operating as both target acquisition and air defense radars is truly a revolutionary concept that could have significant cost ramifications for future system developments.

The sharing of components should be a base requirement for any 21st century radar acquired. Utilizing common hardware components in the radar will have a significant impact upon the base acquisition cost, logistics, and lifecycle support. Instead of purchasing and supporting three different microprocessors, power supplies, transmitters, and receivers, acquisition managers would now have to only acquire one basic type that would be adapted through software to meet the unique military requirements of air surveillance and weapons locating.

Vendors typically offer discounts for large quantity buys. The most significant cost drivers for the Firefinder program was the density of radars to be acquired. The United States bought a total of 96 AN/TPQ-36 and 72 AN/TPQ-37 Firefinder radars over a 15 year procurement cycle. Contractors allocate developmental cost across the total number of items to be procured. Hence, the larger the procurement base, the lower the cost of each individual radar.

Using the same basic components, reduces the logistics footprint because units would no longer be required to carry parts for three different types of radars. One repair part would therefore fit all three. In terms of reducing the logistics footprint, the training for the maintainer would be reduced significantly because they would be dealing with one fundamental weapon instead of three.

SOFTWARE CONSIDERATIONS

During the cold war era, automated systems were in their infancy and limited in their ability to do multi-tasking; therefore, these systems were not designed to do collaboration or information sharing between multiple sensors and the shooter. Instead, each system was built for point-to-point communications, one sensor (radar) to one shooter. While this was a highly efficient and effective method for operating on the battlefield during the 20th century, it is not as effective in the 21st century. Additionally, during the 20th century computers were severely constrained in their memory and processor capacity. This necessitated a software architecture

that was tightly coupled to the hardware architecture, making significant changes to the overall system's architecture difficult and cost prohibitive.

Today, the software architecture is no longer constrained by memory and microprocessor capacity. This has allowed the developers to open the system architecture and design systems with an architecture that facilitates future growth and expansion at a nominal cost. The addition of an open systems architecture to platform development also allows the developer to change the hardware platform at some point in the future without having a major impact on the software structure. The payoff for the warfighter is the realization of a highly capable system in less time with upgradeable hardware.

The software that drives the 21st century radar must be adaptable and expandable. Reviews of major software efforts indicate that systems with open architectures are expandable to accommodate system growth. These systems have high cohesion and lower total life cycle cost. Consequently, an open software architecture should be the foundation for any developmental efforts.

JOINT VISION 2020

The use of COTS, an open software architecture, and the five tenets of Joint Vision 2020 form a solid foundation for building a robust open network architecture. Microprocessor capability improves in capability and capacity about every six months.

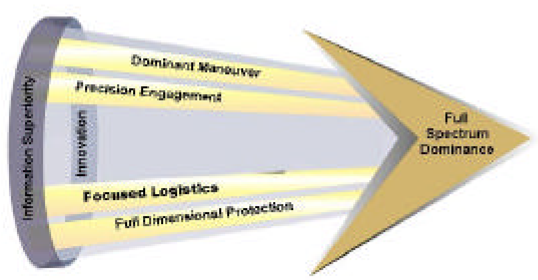

FIGURE 2 JOINT VISION 2020 OBJECTIVES

The 21st Century weapons locating radars must provide the commander with the ability to seek out deeper indirect fire targets, identify the caliber of those targets, and focus engagement

assets to quickly eliminate them as players on the battlefield. The air defense and surveillance radar must provide the commander with the capability to locate and track-fixed wing and rotary aircraft, and determine if those aircraft are friend or foe.

As the Army revises its modernization plan to focus upon the implementation of Joint Vision 2020, innovative thinking is required to revise the battlefield radar employment concept. Combat and Material Developers must come together to focus upon protecting the force, meeting the precision engagement objectives, achieving synergy between sensors and shooters, expanding the radar's area of coverage, and developing a strategic vision for battlefield radar employment in the 21st Century.

Precision engagement, a tenet of Joint Vision 2020, is defined as the ability of joint forces to locate, surveil, discern, and track objectives or targets; select, organize, and use the correct systems; generate desired effects; assess results; and reengage with decisive speed and overwhelming operational tempo as required, throughout the full range of military operations.[27]

A fundamental characteristic of precision engagement is the linking of sensors, delivery systems, and effects.[28] Clearly the capabilities of today's battlefield radars are enablers that would help the commander achieve some of the Joint Vision 2020 precision engagement objectives; however, it is the concept of networked sensors that provide the commander with a decisive force multiplier in expanding the depth and breadth in the amount of space a brigade sized unit could cover.

NETWORK CENTRIC WARFARE

Network Centric Warfare is the central concept for developing a cost effective networked radar architecture. It represents how we will fight in the information age. Common hardware and flexible software are the catalyst to fuel network centricity and make network centric warfare a reality. Figure 3 is a representation of the military as a Network-Centric Enterprise.[29]

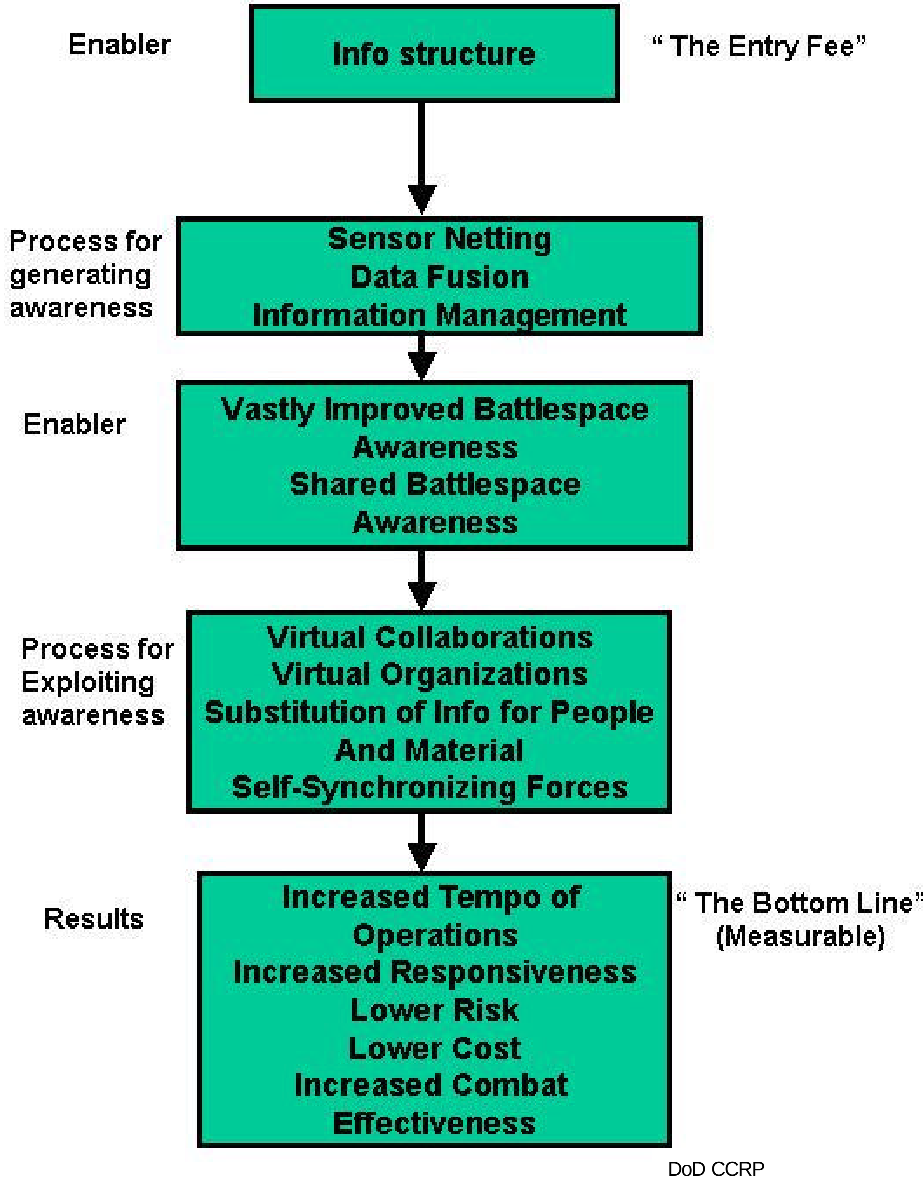

FIGURE 3 NETWORKCENTRIC ENTERPRISE

In this enterprise, a solid info structure allows for the creation of shared battlespace awareness and knowledge. This shared structure facilitates the connecting and fusing of sensors, decision makers, and shooters into a cohesively linked force.[30] The combination of the information, intelligence, and shooters helps the warfighter to maximize effectiveness and increases battlefield responsiveness.

The network centric enterprise architecture presents the potential for the Warfighter to increase the speed of command and control by allowing information to go up, down, and sideways at the speed of light.[31] Early experiments with digital systems indicated that these systems offer tremendous increases in battlefield awareness. This fact was highlighted during the Force XXI experiments at Fort Hood, Texas. Colonel Charles Green noted, "Individual sensors can be effective in locating individual targets, but networks of sensors enable a higher operational tempo."[32] The foundational components for this network centric enterprise architecture are three grids? an information grid, a sensor grid, and an engagement (shooter) grid.[33]

The information grid is the backbone of network centric warfare. It provides the infrastructure for receiving, processing, transporting, storing, and protecting information.[34] Data security and validation is a key requirement for the information grid. With a secure information infrastructure, commanders can be assured high speed access to critical tactical and operational data.[35] The Force XXI experiments demonstrated that networks facilitate cross-cuing among sensors; thereby, demonstrating the speed with which commanders could assess critical targets.[36]

The sensor grid is composed of multiple sensors. These sensors include dedicated sensors, platforms, space, and cyberspace based sensors all connected through the information grid to distribute information across the force.[37] Networking the sensors together facilitates the creation of engagement quality awareness. For the battlefield radars, they could be specifically tasked to support the quick sensor-to-shooter links necessary to engage fast movers and scud missiles.[38]

The engagement grid represents the culmination of all of the shooters. It makes the most of the battlespace awareness provided by a network-centric environment.[39] The fusion of information in the engagement grid allows land, sea, and air shooters the ability to mass and engage the enemy with depth, agility, and increased lethality.[40] Networked sensors allow the shooter to have a complete common operational picture and undertake cooperative engagements.[41]

These three-shared grids then facilitate the connecting and fusion of sensors, decision makers, and shooters into a cohesively linked force. The best example of fused sensors was in the 4th Infantry Division's use of digital networks to allow for simultaneous near real-time connection of multiple consumers to intelligence reports.[42] This enhancement allowed for greater synthesis of information resulting in timelier decisions and quicker engagements in the battlespace.

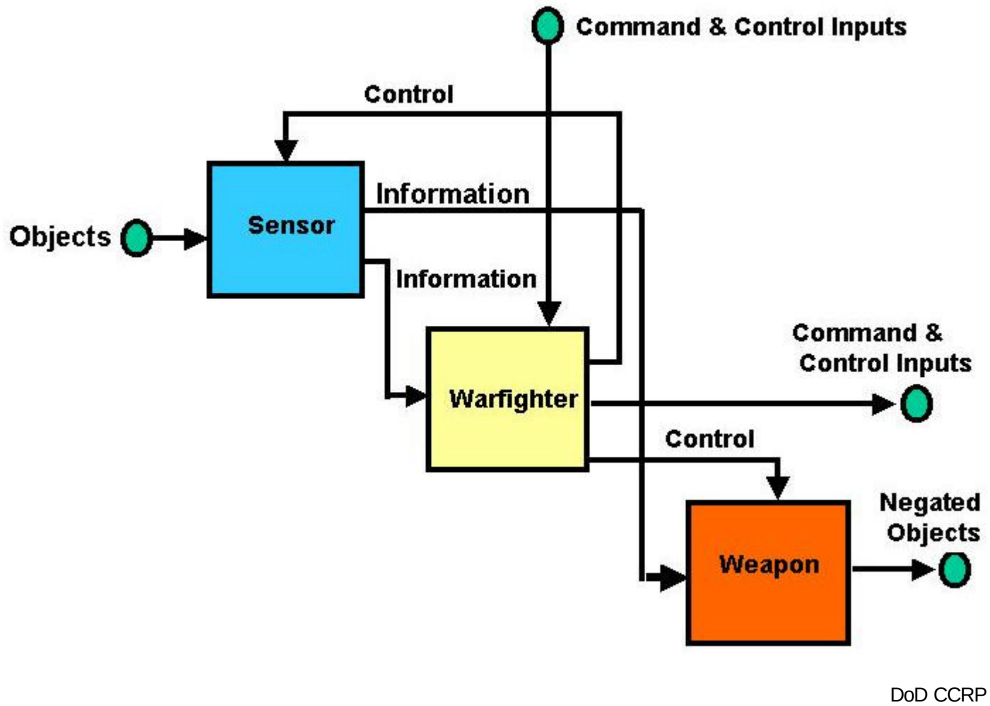

FIGURE 4 PLATFORM CENTRIC SHOOTER

In a platform centric environment, grid-to-grid interactions, i.e. sharing of information among battlespace entities, are not prime considerations. Instead the focus is upon responsiveness between the sensor and shooter. During the 20th Century, speed and responsiveness facilitated rapid engagement. In the 21st Century, the complexity and depth of operations presents challenges to the deployed battle forces that render speed and responsiveness alone obsolete. A systems of systems networked environment where information is shared across vast areas is the optimal means for commanders to enhance the capabilities and survivability of their forces. Figure 4 shows how platform centric sensors are tied directly to the weapons platform[43]. In the platform centric environment, the direct link

between sensor, warfighter, and shooter is analogous to a point-to-point telephone call or one-to-one contact with no sharing or collaboration of information with an outside party.

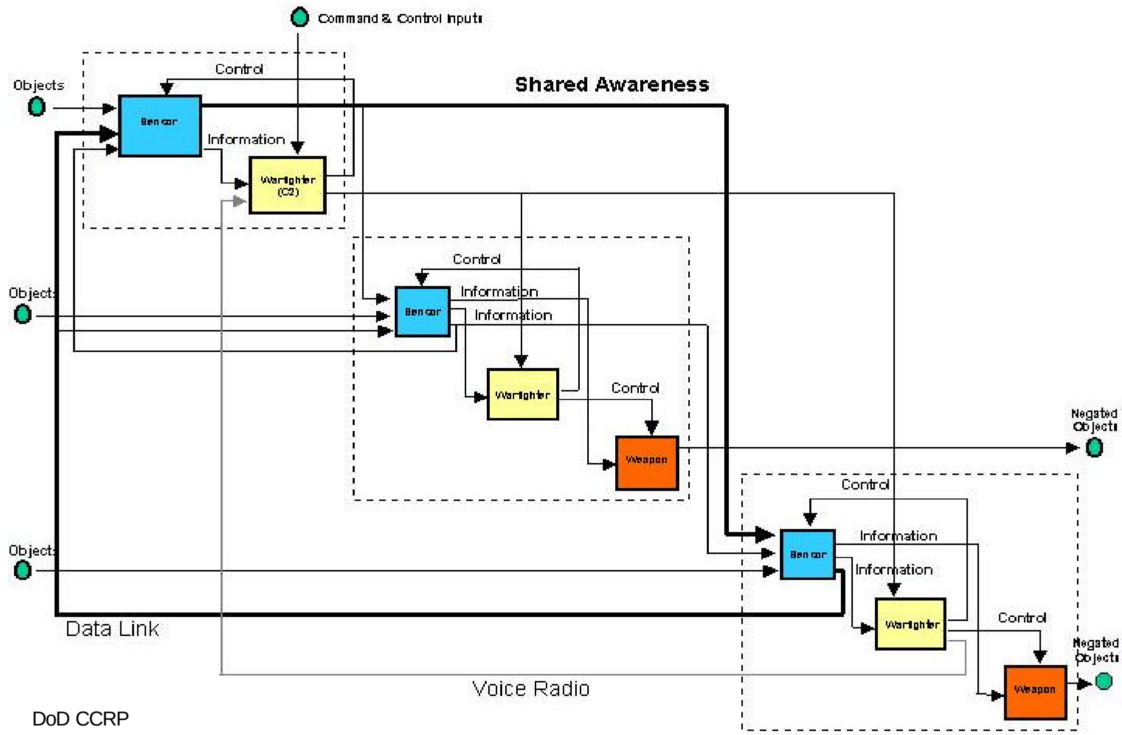

FIGURE 5 NETWORK CENTRIC OPERATIONS

In contrast to the platform centric environment, a network centric environment integrates the multiple grids to gain synergy of effort. In this environment the shooters will be able to accept sensor inputs from multiple sources; thereby, enhancing their effectiveness in timely engagement of the enemy. Figure 5 shows how three of the same type sensors that are multi connected can increase their linkages to other shooters and sensors if they are able to share information.[44]

A networked architecture makes use of Metcalf's Law to illustrate the potential value gained through the use of a network.[45] Under the Law, theory states that there is an exponential increase in the network as the number of nodes in the network increases linearly.[46] In other words, where n= the number of nodes, the potential increase in effectiveness is n^2. Layton found in his study of network-centric computing that the large numbers of heterogeneous

computational nodes in the network generate the real "power" of the network.[47] This is illustrated in the networked sensor example in figure 5; the potential increase in the effectiveness of three networked sensors would be 6, where n=3 and $3^2=9$.

The sensor-to-shooter links in effect today are essentially non-network centric players. While there is tremendous speed in this approach, there is no real power. To illustrate two radars and their linked shooters, Figure 6 shows the area that these sensors and shooters individually could cover.[48]

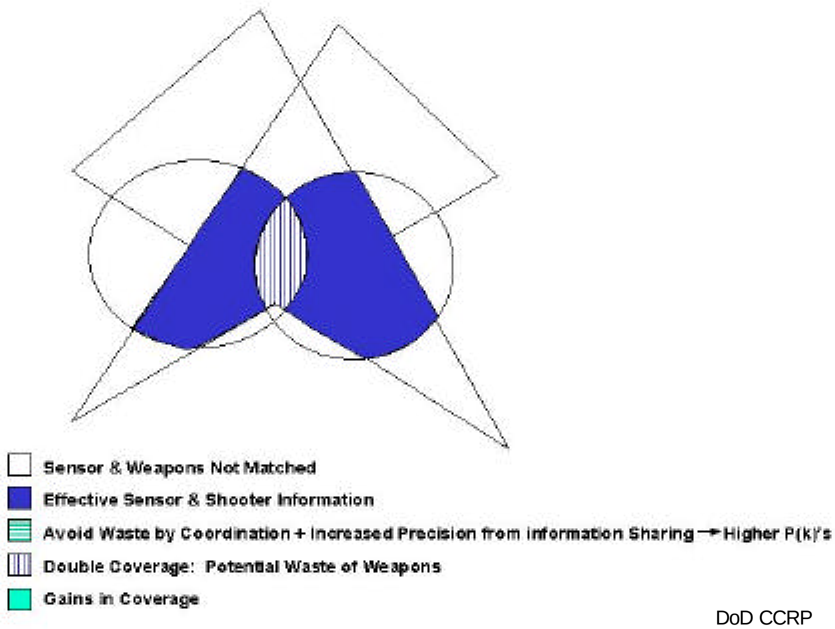

FIGURE 6 INDIVIDUAL SENSORS

On a linear battlefield, this type of coverage would be optimal because it would segregate the sensors into specific limited areas of responsibility. On the 21st century battlefield, this type of responsibility would decrease effectiveness. By combining two radar's individual area of coverage in a network centric environment, there is almost a 50% gain in coverage.[49] This additional coverage would go a long way to support the Stryker Brigade Combat Team (SBCT). During his recent Warfighter exercise, COL Bailey, Bde Cdr, 3rd SBCT, stated that he needed a radar structure that could cover an area 50-by-50 kilometers.[50] He advocated three radars deployed linearly; this same area could be covered with two networked radars as shown in Figure 7.

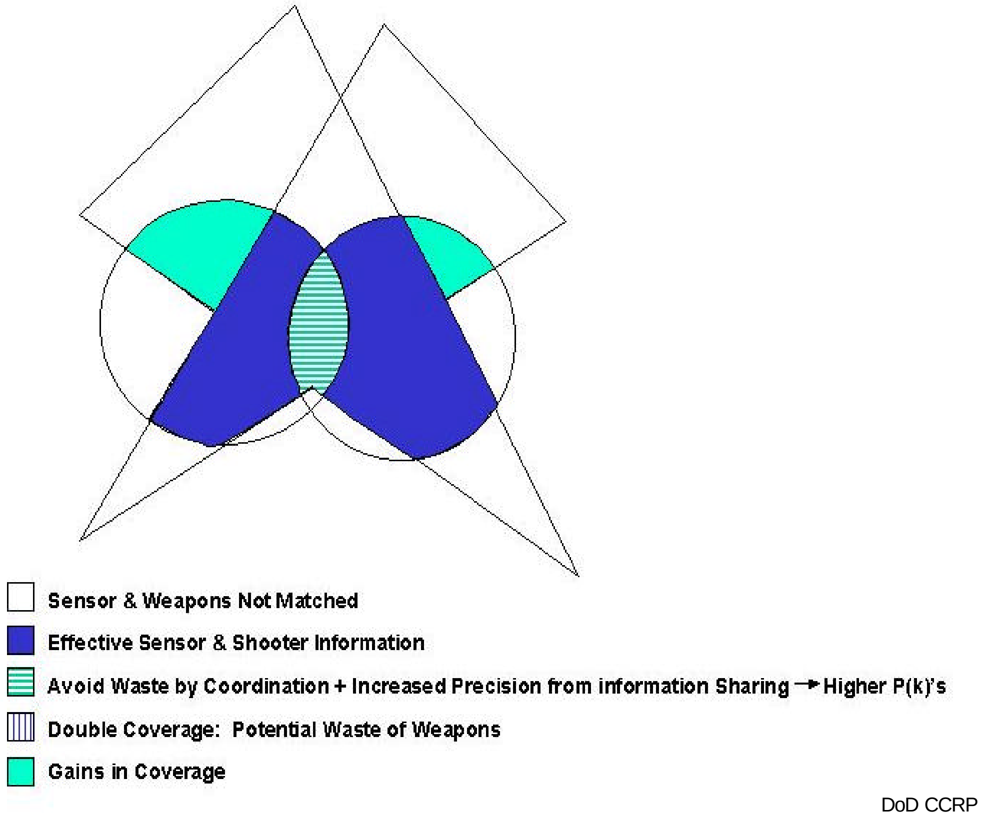

FIGURE 7 NETWORKED SENSORS

While the radars in this example may be geographically dispersed over a larger area, their ability to collaborate in virtual space will be a combat multiplier for the warfighter. Success of the 4th Infantry Division during the Division XXI Advanced Warfighter experiment illustrates the power of networked systems. On the commercial side, the well-publicized case study of the success at Boeing in designing the 777 proves the value of networking through virtual collaboration.[51] Using sensor inputs from other areas on the battlefield will allow the commander to form a more perfect common operational picture; thereby, reducing the necessity to deploy his own resources to identify and define the enemy's strengths and capabilities.

Network centric warfare will facilitate the dispersion of the battlefield radars and their associated weapons firing platforms. This ultimately will reduce the battlespace footprint, which will in turn reduces risk because a dispersed force avoids presenting the enemy with an attractive high-value target.[52]

OBJECTIVE FORCE RADAR ARCHITECTURE

The objectives of Joint Vision 2020 and the network centric warfare concept form a solid framework for developing a radar architecture capable of supporting the 21st century objective force. Radars developed using these principles will have the capability to support and sustain a highly mobile force in multiple theaters and operational environments. In order to build a radar architecture within this framework, combat and material developers must take three factors into consideration: system requirements for the radars, integration of the radars into the intelligence sensor grid, and the tactical employment of the radars within the battlespace.

Of these three factors, defining the system requirements is the most difficult task because it involves multiple combat and material developers. System analysis indicates that weapon locating, air surveillance, and air defense radars share many of the same commonalities. Consequently, developing a single document that list a complete set of systems requirements is not an overwhelming task. Table 1 (on page 24) extracted from the Performance Specification of the multi mission radar illustrates that it is both possible and feasible to articulate multiple system requirements in a single document.

Typically weapons locating radar requirements are defined by the U.S. Army Field Artillery Center and development of those requirements are supported by the Program Executive Office for Intelligence Electronic Warfare and Sensors. Air defense radar requirements are typically defined by the U.S. Army Air Defense Center and development of those requirements are supported by the Program Executive Office for Air and Missile Defense.

The requirements definition concept used by the CECOM RDEC to define the requirements for the multi mission radar is an excellent requirements definition model. Using this model, the CECOM engineers are able to bring both the Air Defense and Field Artillery material developers together and define a collective set of requirements for a multi-mission radar in one document. The multi mission radar defined in their performance specification is an excellent starting point for defining a short-range 21st century radar because it addresses the three types of radars? weapons locating, air surveillance, and air defense used on a 21st century battlefield. A shortcoming of the specification is that it does not address the concept of network centricity which would have to be added in order to fulfill the framework requirements for the 21st century radar.

The requirements defined in the system specification for the AN/TPQ-47 Radar is an excellent starting point for defining the requirements for a long-range 21st century radar. This radar currently supports the concept on network centricity because of its interface with the Army Battle Command System (ABCS) and the differentiation of fires between heavy, medium, and light artillery and mortars, rockets, and missiles out to a maximum range of 300KM. One shortcoming of the current specification is the horizontal exchange of information between other sensors. By adjusting the system specification to allow for the horizontal exchange of information, this radar would be fully integrated into the sensor grid of the network centric warfare concept.

Integration of systems does not happen by chance; it must be engineered as a part of the system's architecture. The 21st century radar must be integrated into the sensor grid of a network centric battlefield. An integrated network of sensors will be a true multiplier. If we were to apply Metcalf's law to the existing 13 radars in a typical heavy division on today's battlefield, we would see a potential increase of 169 in effectiveness. Figure 7 illustrates the benefits of integrating two sensors. In this example, there is a 50% net increase in coverage by networking two sensors together. Integrating the radars into the sensor grid would have a similar effect.

The operational concept for the objective force represents the first major change in U.S. fighting doctrine since World War II.[53] The foundations for the concept extend back to the Louisiana Maneuvers and Force XXI.[54] Under this new concept, the Army's echelonment is no longer organized around Corps, Divisions, and Brigades. Instead the echelonment is focused on two basic groups--the Unit of Employment (UE) and the Unit of Action (UA).[55]

The UE represents the higher echelon forces that integrate and synchronize forces at the higher and operational levels. The July 02 draft of the Operations and Organization (O & O) concept describes the UE as a highly capable command and control (C^2) entity exerting C^2 over all Army, joint, and multinational forces.[56] Currently the UE is envisioned to be a multifunctional Headquarter (HQ) nucleus with embedded joint staff elements supplemented with a standard compliment of subordinate communications, sustainment, and Reconnaissance Intelligence Surveillance and Target Acquisition (RISTA) organizations[57]. In this structure, there is a counterfire cell which controls the long range counterfire radars similar to the way the Division Artillery Counterfire cell employs the Q-37 today. A key concept of the UE is its flexibility. This organization can be expanded into a larger formation through tailoring to meet any contingency.

Subordinate units of action assigned to the UE would be tailored for contingency or ongoing stability operations, which include maneuver, fires/effects (lethal/nonlethal), Intelligence Surveillance Reconnaissance (ISR), maneuver support, force protection, and maneuver sustainment command.[58] In the UE O & O, there are several key technological assumptions:

- Advances in ISR, precision, and lethality (range, rate of fire, effects, etc.) will result in engagements taking place at greater ranges, with greater effects, and lead to more rapid tactical decisions, in turn permitting tactical units to transition immediately to subsequent engagements without pause.

- Improvements in durability, reliability, fuel efficiency, and precision munitions will reduce sustainment demands and sustainment infrastructure and increase tooth-to-tail ratios.

- Improved sensors, sensor fusion, ISR, communications, and knowledge networking will lead to higher levels of situational understanding, enabling more effective application of combat power and a shift to a non-contiguous battlefield framework, with greater dispersion and decentralization of forces.

- Advances in precision, [Command Control Communications Computers Intelligence Surveillance Reconnaissance] (C4ISR), stealth, and mobility will combine to reduce risk to forces and enable transition to a force protection and survivability approach no longer as dependent on heavy armor and passive protection.

- Improvements in [Command Control Communications Intelligence] (C3I) capabilities and staff processes will underpin decision superiority, improve anticipatory planning, permit continuous assessments, and enable better, faster decision-making

- Operational agility and mobility will improve significantly to enable UE formations to act throughout the enemy's entire dispositions

- Capability advances across the multiple domains described above will permit the design and organization of smaller units with combat capabilities exceeding those resident within current forces[59]

These assumptions are helping planners to change the paradigm for campaign planning. Campaigns of the 21st century will no longer focus upon a time-consuming phased attrition-based campaign.[60] Instead, future joint operations will emphasize rapid strategic responses by all arms, leading immediately to the conduct of synchronized shaping for decisive operations throughout the depth and breadth of the area of operation to achieve rapid collapse. This was proven during the Force XXI experiments. Major General Griffin noted, "employing technology with digitized systems enhances [the division's] its warfighting capability in situational awareness, lethality, survivability, and battle command."[61]

The radars in the UE will rely on a knowledge-based C4ISR network of networks, vertically and horizontally integrated from strategic to tactical level. Drawing information, updated in near real time, from the Army Battle Command System (ABCS), unmanned aerial vehicles, and an assortment of intelligence databases these radars will be focused on improving target acquisitions and accelerating the decision-action cycle. Fusing data through a robust communications grid to a knowledge based network will greatly improve the COP and lead to a more effective application of combat power on a non-contiguous battlefield.

In change 1 to TRADOC PAM 525-3-90 O&O, the Unit of Action (UA) does not have a traditional Field Artillery Battalion; instead it has a Non-Line of Sight (NLOS) Battalion which has two missions. Its primary mission is to provide destructive, suppressive, and special purpose fires to enable the UA to conduct decisive operations.[62] Its secondary mission is extended range counter-air engagements against Rotary Wing (RW) and Unmanned Aerial Vehicles (UAV) threat in accordance with Joint Integrated Air Defense System rules and procedures.[63]

It is envisioned that three of the six radars employed by this battalion will perform the counterfire mission to provide a vital role in force protection.[64] The ongoing warfighting experiments with the SBCT at Fort Lewis, Washington, indicate that the UA will engage an adversary on a 40-by-40 to 50-by-50 kilometer area.[65] According to COL Bailey, Bde Cdr 1st SBCT, he needs three radars, two Q-36s and one Q-37, to adequately cover his brigade area of responsibility.[66] The SBCTs are a prelude for the objective force. During a recent Battle Command Training Program (BCTP) Warfighter exercise, the SBCT was operating in a 100-by-100 kilometer area of operation as it began its stability and support operations mission.[67] Consequently, designers of the objective force should make the 100-by-100 kilometer area the standard for the UA.

Artillery forces deployed in Afghanistan have indicated the need for both omni-directional and long-range radars.[68] Accuracy is not the premiere requirement for the short-range radar. Instead, this radar's premiere requirement is omni-directionality so that it can provide a general area or location for the purpose of redirecting patrols or aircraft to the enemy.[69] The long-range radar would have the accuracy requirement for focusing on Named Areas of Interest (NAI).[70] Together these radars would afford the commander total coverage.

Battles in the 21st century will be similar to those experienced by our forces training at Fort Lewis and supporting operations in Afghanistan. The lessons learned by our forces must be applied to the objective force radar structure if we are to maximize the engagement forces capabilities. Consequently, four of the six UA radars should be short-range omni directional, and two radars should be long range. This radar composition would address experiences by the SBCT and the lessons learned from soldiers fighting in Afghanistan.

CONCLUSION

Determining the location and identity of our adversaries will be one of our most significant challenges in future battles.[71] Although we will see vast improvements in the performance and unit cost of sensors (radars), the real payoff will be from how the sensors are integrated into the battle space.[72] Unlike the "thick clients" of today, sensors on the 21st Century battlefield will transfer information via "thin clients" which will require very little processing and data storage.[73] This adaptation will eliminate "stovepiping" and allow the radar to be weapons platform independent.[74] As a part of the sensor grid, the battlefield radar is an invaluable tool that gives the commander a decisive edge on enhancing information dominance on the battlefield. The concept of combining weapons locating and air defense radars into a single platform has the potential to significantly increase the intelligence-gathering capabilities of the Warfighter and conversely reduces the total acquisition cost.

The digitization experiments at Fort Hood, Texas, Stryker Brigade experiments at Fort Lewis, Washington, and the design and operational concepts reviewed for this project indicate that it is technically and operationally feasible to build radar network architectures on the future battlefield that reduce the force structure, lower acquisition cost, and improve logistics. The application of the network centric warfare concept will yield a networked radar architecture that is adaptable and capable of supporting a force on the 21st century battlefield. Major General Maples noted in his objective force article, "Networked Fires will be an application within the Objective Force battle command system. As a fires system-of-systems, it will give commanders the ability to apply full-dimension [precision fires] effects solutions in near real-time throughout their battlespace."[75] A networked radar architecture supports networked fires by providing the Warfighter with the greatest flexibility in total area coverage; thereby, making the radars highly adaptable for fighting anywhere in the world. The ability of our adversaries to move rapidly and

make maximum use of cover and concealment will make the radar an indispensable tool in determining his exact location and identity in future battles.[76]

Radars that are networked help to support the UE's long-range fires requirement with precise targeting. By dynamically establishing sensor-to-shooter linkages based upon changing conditions on the battlefield, networked radars will provide the Fires and Effects Cell (FEC) total connectivity to the NLOS battalion.[77] Radars assigned to the UA force structure clearly support the objectives of Joint Vision 2020? Full Spectrum dominance through a highly integrated and rapidly deployable force. As a part of this structure, the UA 21st century radar will provide 360° coverage for protection and a link to the UE long-range shooters.

Radars built upon an open systems architecture and COTS hardware, as its foundation will reduce the total system cost per radar. With air defense, air surveillance, and weapons locating radars sharing the same basic component, economy of scale can be realized. The Army can purchase and stock one type of radar component versus four different types. An analysis of a recent contract awarded by CECOM for additional AN/TPQ-36(v)8 radars indicated that the system cost were substantially lower in the first two years. In the latter two years of the contract the system cost increased primarily because of the risk associated with obsolete parts procurement. Consequently, there was potentially a 25% savings in the total acquisition cost had the purchase been limited to a two year versus a four year contract. If the Army were to consolidate the radar requirements into two platforms, a long range and short range radar, utilize common components in the radars, and reducing the total acquisition time, a significant savings of 25% or greater could be realized. Research and Development (R&D) cost would be recouped over a larger base, making the system more attractive for foreign customers. Material and Combat developers will not be required to spread personnel over multiple developments but can instead focus scarce engineering resources on building the best product possible for the Warfighter.

By applying the Network centric paradigm, six short-range radars can be eliminated from the force structure. At approximately $5M per radar, this savings will be significant for force designers. Currently there is no funding for upgrading Sentinel in the Army's 2002 Modernization Plan. Consequently, a 21st century radar that performs both air defense and weapons locating will update and integrate the force to meet the needs of the force commander. As a start, the battlefield functions identified in the Multi-mission Radar would be an excellent

starting point for a network centric short-range radar. This would have the effect of building upon a proven base, which will reduce the total acquisition time for the system. The AN/TPQ-47 radar has many of the requirements required for a long-range 21st century radar; consequently, planners should expand upon this radar's system specification to meet the network centric requirements.

Radars that share common components will significantly reduce the logistical footprint. Having two basic types of radars, one for short-range acquisitions and one for long-range acquisitions, instead of four different radars helps to reduce the logistical burden on a taskforce. In a common environment, the amount of spares to be transported would be reduced 50% - 75% because there is no longer a requirement to maintain four different types of the same item.

In terms of total logistics, the training base would also be affected. Training for the maintainers would be reduced from four systems to two systems. This would afford the maintenance community more time for troubleshooting and diagnostic training instead of giving the young maintainers a broad brush of systems maintenance.

Changing system requirements during development is the most significant cost driver in building a radar. A firm collective set of requirements for the objective force radars is needed to preclude these highly disruptive changes. Since the Training and Doctrine Command assigns combat developer roles, they should define a battlefield concept and serve as the arbitrator to decide who will take the lead in developing a set of specifications for the 21st century radars. Building a network radar architecture that will meet the Army Chief of Staff's timeline is achievable within the Army's current funding limits. Discipline, dedication, and an incremental developmental philosophy on the part of the combat and material developers will bring the vision to fruition.

WORD COUNT = 6,963

TABLE 1 - PERFORMANCE SPECIFICATION

Performance Area	Specification
<u>Air Defense Surveillance (ADS)</u>	
Target Minimum Velocity	40 m/s
Target Maximum Velocity	1,000 m/s
Maximum Maneuvering	3G
Probability of Acquisition (Pa)	Pa = 90% @ 1 square meter RCS
Surveillance Coverage	Azimuth: 360 degrees Elevation: 25 degrees (selectable within –10 to +55 deg) <u>Range @ 1 sm RCS</u> Minimum Range: 5 km Maximum Range: 100 km Track Coverage: Azimuth: 360 degrees Elevation: –10 to +55 deg
Altitude Coverage	Minimum Altitude: 300 m AGL Maximum Altitude: 15 km AGL
Tracking Accuracy	Within 150 meter (1 sigma) of true location
Track False Alarm Rate	1 per 3 hours
Track Report Rate	1 per 3 seconds
Number of Target Tracks	400
<u>Counterfire Target Acquisition (CTA)</u>	
Detection Condition:	
Terrain Masking	An Optical Terrain masking angle ≤ 25 mils
Angular Elevation Rate	100 mils/sec
Angular Azimuth Rate	100 mils/sec
Target Elevation Above Mask	At least 40 mils above terrain mask, at distance equal ≥ min instrumented radar range
Range	Min Range: 3 km Max Range: 30 km Location over 1,600 mils Azimuth sector when ascending portion of the interceptor trajectory is contained within this sector.
RCS	-27 dBsm
Muzzle Velocity	Locate weapons firing within a muzzle velocity between 100 m/s and 900 m/s
Antenna Traverse	Azimuth: +/- 3200 mil from ref. Elevation: -50 mils to +200 mils
Azimuth Coverage	1600 mils
Terrain Elevation	142 mils
Probability of Location	85%
Location Accuracy	Location within 50%: 35 m or 0.35% or range, whichever is greater. Location within 90%: 90 m or 0.9% or range, Whichever is greater.
Multiple Weapon Location – 85% Prob. Of	100

Performance Area	Specification
Location	
In-bound/Out-bound Mode of Operation	In-bound/Out-bound Selectable
Hostile Projectile Impact Prediction – 50% CEP	500 m or 2% of fire range (whichever is greater)
Friendly Impact Prediction	30 m or 0.3% or range
False Location Rate	1 per 6 hours
Target Classification	Classification on Mortar, Artillery, and Rocket weapon systems and subclass of these weapon systems.
<u>Active Defense Fire Control</u>	
Coverage – Slew +/- 3200 mils	Azimuth: fixed sector Elevation: -10 to +55 deg
Range	10 km
Track Accuracy @ 10 km	Cross-Range: 50 m Range: 15 m
Number of Simultaneous Target Engagements	1
<u>Air Traffic Control</u>	
Target Characteristics	Minimum Velocity: 40 m/s Maximum Velocity: Same as ADS Maneuvering Targets: Same as ADS
Probability of Acquisition	Same as ADS
Acquisition Range	Same as ADS
Surveillance Coverage	Same as ADS
Altitude Coverage	Minimum Altitude: 300 m AGL Maximum Altitude: Same as ADS
Range Resolution	Resolve 2 aircraft with same RCS, Azimuth and elevation, separated by 755 feet with Probability of 90%
Azimuth Resolution	Resolve 2 aircraft with same RCS, range and elevation with min Probability of 90%, separated 4 degrees
Tracking Accuracy	Same as ADS
Track Report Rate	Same as ADS
Number of Tracks	Same as ADS
False Track Alarm Rate	Same as ADS
Remote Control and Display Unit	Distance: 100 m
Mobility and Transportability	Roadworthy for self-transport and transport on single C-130 aircraft

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